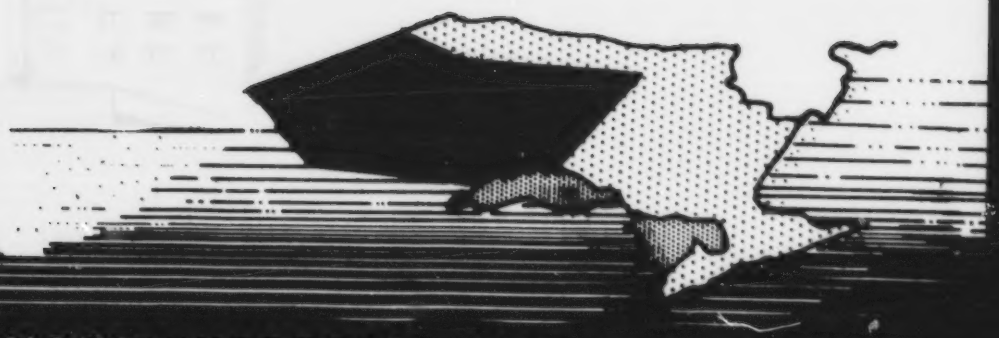

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PRE-COMMERCIAL THINNING OF JACK PINE

by

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ABSTRACT

The pre-commercial thinning of jack pine (Pinus banksiana Lamb.) is an important silvicultural control method over the density and development of natural or artificially seeded stands. Compared to unthinned controls, growth responses from pre-commercial thinning of jack pine have resulted in higher diameter increments, lower total volume and basal area per hectare, higher merchantable volume per hectare and lower mortality, but no difference in height growth. Thinning is most economically feasible when undertaken once the lower branches begin to die (ages 6 to 12 years) on site class 1 and possibly on the upper half of site class 2 stands where sawlogs are the end product. Motor manual thinning using brush-saws, or as an alternative, manual thinning with axes and sandviks are the most efficient means of pre-commercial thinning. Manual thinning provides the opportunity for crop tree selection which is one of the most important considerations of the thinning operation. Crop trees must be dominant, within the prescribed spacing, have low taper, small branch diameters and be relatively free from disease and damage.

TABLE OF CONTENTS

ABSTRACT i

Acknowledgements iii

INTRODUCTION 1

JUVENILE STAND DEVELOPMENT 2

WHY THIN? GROWTH RESPONSES 3

- Diameter 4
- Height 4
- Total Volume and Basal Area Per Hectare 4
- Merchantable Volume Per Hectare 5
- Mortality 5
- Stem Taper 5
- Wood Quality 6

WHY THIN? PRODUCT CONSIDERATIONS 7

WHEN TO THIN 9

WHERE TO THIN 10

HOW TO THIN 10

- Manual and Motor-Manual Thinning 11
- Mechanical Thinning 12
- Chemical Thinning 14

OTHER CONSIDERATIONS 15

- Biological Considerations 15
- Insect and Disease Susceptibility 16
- Damage 17
- Payment Method 17
- Economic Considerations 18

SUMMARY AND CONCLUSIONS 20

LITERATURE CITED 22

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INTRODUCTION

Jack pine (Pinus banksiana Lamb.) is one of the most important commercial species in northwestern Ontario. The species constitutes some 38% of the volume harvested, of which 25% is used for sawlogs, ties and poles, and the remaining 75% used for pulpwood production (Davison 1984; Kennedy 1984). In addition, approximately 80% of the area regenerated annually in northwestern Ontario is to jack pine. Much of the jack pine regeneration effort following harvesting or fire has been site preparation followed by direct seeding. This has proven successful on shallow, stony sites, sand plains, and outwash deposits. In addition, natural seeding from jack pine's serotinous cones after wildfires can result in successfully stocked stands.

Jack pine stands regenerated by either natural or artificial seeding seldom result in the optimum use of the site potential. Stocking and density can be excessively high, although understocking is also a problem if seedbed and seeding requirements are not met (Riley 1973). Conventional site preparation and seeding methods allow a certain degree of control over stocking; however, density is less readily regulated. Densities of between 30,000 to 60,000 stems per hectare (ha) are not uncommon, and young stands up to 120,000 stems per ha have been reported after fires (Bella 1974). Seeding of jack pine usually results in stands that have grouped, rowed or random distribution patterns.

Thinning is a form of density control that may have to be considered if optimum use of the site potential is to be realized. The main objective of thinning is to maintain a high volume increment of quality wood in a stand by adjusting the number of stems. In essence, stand thinning results in concentrating the volume increment on fewer stems. Thinning may be classified as pre-commercial or commercial. Pre-commercial or non-commercial thinning refers to the thinning of immature stands with no financial return from the

material harvested. Commercial thinning on the other hand infers that the thinning of stands will result in some financial return from the material harvested. Both pre-commercial and commercial thinning can be biologically desirable and economically feasible if conducted at the proper time in the life of the stand (Riley 1973). Most authors agree that maximum biological benefits occur when thinning is undertaken early in the life of a stand, i.e. pre-commercial thinning.

The objective of this review is to synthesize the current literature on pre-commercial thinning of jack pine in terms of growth response, method of thinning, wood quality, end product and economic considerations. In addition, the major gaps in knowledge will be identified and possible future areas for research and development suggested.

JUVENILE STAND DEVELOPMENT

Aerial and natural seeding of jack pine has produced many successful stands in northwestern Ontario. Density variability is often associated with aerially seeded stands, where well stocked areas are interspersed with poorly stocked areas (Smith 1984).

Jack pine is usually aerially seeded at a rate of 50,000 seeds per ha or seeded during site preparation at a rate of 15 viable seeds per scalp in order to achieve satisfactory stocking levels of 60% or better (Smith 1984). Often these rates are not adjusted for ingrowth which can be significant during the early years of a stand's development. Lyon and Thomson (1979) found that if the rate of seeding, amount of receptive seedbed, weather conditions following seeding and the amount of ingrowth are not all considered, then high density conditions may result.

Jack pine is an intolerant species which will form even-aged stand with little variation in height and individual crown width (Vezina 1964). Under high density conditions the growth of these stands is often slow and can be susceptible to winter storms and heavy snowfalls which flatten sizeable areas. In these conditions the trees are too spindly to recover and the stand develops dense overstocked groups of trees with intermixed open areas (Roe and Stoeckeler 1950; Godman and Olmstead 1962; Gary and Watkins 1985; Schnekenburger et al. 1985).

Jack pine must grow in dense stands to overcome its competitors by crown closure. Crown closure is also required by jack pine for self pruning. Brown (1984) suggests that jack pine will not endure juvenile densities less than 2500 stems per ha. At a density of less than 1125 per ha, 50% of its volume is in heavy branches. Brown's (1984) work was qualitative and a recent review by Willcocks et al. (1988) found no quantitative data to support his claim.

High initial densities appears to be a prerequisite to develop good early growth and form of jack pine, but coupled with this is a slowdown in growth between the ages of 10 and 20 years (Wilson 1952; Bella and DeFranceschi 1971). In order to improve growth and product form, pre-commercial thinning of jack pine may be necessary.

WHY THIN? GROWTH RESPONSES

The results from thinning research in jack pine and its close relative, lodgepole pine, indicate that thinned stands when compared to their unthinned controls will have: higher diameter increments; no difference in height growth; lower total volume and basal area per hectare; higher merchantable volume per

hectare; lower mortality; and increased stem taper. In addition, thinning influences wood quality properties, although this effect is not well documented.

Diameter

Higher diameter increment results from pre-commercial thinning (Wilson 1952; Smithers 1957; Bella and DeFranceschi 1974). By decreasing density, there is an increase in average tree diameter (dbh). Current annual diameter increment increases with the intensity of thinning. Bella and DeFranceschi (1974) found that trees in larger-than-average size classes show the greatest absolute increase in diameter growth after thinning. Smaller trees, however, may have a higher relative growth rate.

Height

Height growth is not influenced by thinning (Buckman 1964; Winston 1977; Smith 1984). Bella and DeFranceschi (1971, 1974) did not find a consistent relationship between height increment and intensity of thinning. Wilson (1952) revealed a tendency to greater height growth on more heavily thinned plots but stated these trends were not well defined. In contrast, height growth shows a stronger correlation with site productivity and soil moisture regime.

Total Volume and Basal Area Per Hectare

Thinning will lower total volume and basal area per unit area (Wilson 1952; Cayford 1961; Waldron and Cayford 1961; Buckman 1964). By reducing the number of stems and decreasing the density, there is a reduction in the total volume production of a stand. Wilson (1952) and later Cayford (1961) conducted measurements from a thinning of an 18-year-old jack pine stand in Saskatchewan

to spacings of 1.2, 1.5 and 1.8 m. They concluded that the total volume of the thinned area was less than the control; hence, if total fibre production is the sole consideration and objective for the stand (i.e. for pulp), there may be little incentive to thin.

Merchantable Volume Per Hectare

Higher merchantable volume per ha will result from thinning (Wilson 1952; Cayford 1961). By decreasing density through thinning there will be an increase in merchantable stand volume. The stand's volume is distributed on fewer, but larger stems. This point is key for sawlog production as thinning concentrates quality wood production on selected individuals.

Mortality

By decreasing density, there is less loss to mortality (Waldron and Cayford 1961; Cayford 1964; Bella and DeFranceschi 1971, 1974). Cayford (1964) provides 40 year data of the effect of density on mortality from thinning a 10-year-old jack pine stand. He found that the mortality was 95%, 61% and 31% for the control, intermediate thinned and heavily thinned plots respectively. It must be pointed out that more trees are removed by a pre-commercial thinning operation than would probably die from overcrowding. A higher final total volume without thinning results from the higher number of trees.

Stem Taper

Stem taper is a function of diameter and height growth and it ultimately affects the quality of wood negatively. In general, thinning produces a more tapered tree because of increased cambial activity and radial growth towards the

base of the tree (Kramer and Kozlowski 1979). In jack pine, there is a lack of solid data on the effects of thinning on stem taper and is a topic that requires further development work. One study (Buckman 1964), notes there is no significant differences on stem taper from thinning jack pine to spacings of 1.2, 1.8, and 2.4 m. However, Buckman (1964) only examined the first 6 m of trees that averaged 12 m in height at age 27 (22 years after thinning). It appears that early thinning before stands are greatly suppressed will offer more uniform diameter growth rates, thus minimizing taper.

Wood Quality

In general, thinning can result in the development of a larger tree crown, a wider growth ring, and larger branchwood than are present in an unthinned stand (Yang 1987). The increased crown size is frequently followed by an increase in the proportion of earlywood. (Zahner and Oliver 1962; Larson 1967). These changes to the growth and development of the crown can have important effects upon wood properties and product suitability. Just how wide the spacing needs to be before wood quality is affected is unknown for jack pine.

Selective thinning of jack pine at an appropriate age in natural or direct seeded stands can produce higher quality sawlogs than planting unimproved stock at normal or wide spacing (Janas and Brand 1988).

A lower specific gravity of wood can be expected after thinning. Thinning stimulates the production of earlywood which possesses a lower density of wood.

Juvenile wood formation is increased or prolonged after thinning juvenile stands. A close spacing or light thinning will confine the juvenile zone to a smaller central core, whereas a wide spacing will expand the juvenile zone

(Larson 1967). Juvenile wood products have a higher degree of rejection because of dimensional instability (Yang 1987).

Thinning of jack pine has resulted in the transition from earlywood to latewood being more diffuse (Zahner and Oliver 1962). It was suggested that this delay of changeover from large diameter earlywood-like cells to small diameter latewood-like cells is associated with soil moisture depletion. Since there is less total stand crown cover, less transpiration by crowns, more water reaching the ground and less absorption from roots, the availability of water will last longer, thereby maintaining the level of growth-stimulating hormone synthesis by terminal activity.

Fibre length usually decreases as a result of thinning in many species (Yang 1987). However, the impact of thinning appears to diminish with time as the trees utilize and compete for the growing space created by thinning. Data on the influence of jack pine thinning on fibre length appears to be lacking. It would be assumed that since a long fibre is generally desirable for paper making, pre-commercial thinning of jack pine for pulping, and paper making would not be desirable; however, this has not been documented.

Thinning can have an important influence on wood properties and product suitability. Forest managers must be aware of what the implications of pre-commercial thinning can have on the final product. Unfortunately, these impacts are not well documented for jack pine and appear to require additional research.

WHY THIN? PRODUCT CONSIDERATIONS

Before any silvicultural activities are planned or undertaken, goals and objectives must be determined and outlined, either in a Timber Management Plan or in a crop plan. Final expected merchantable yield and rotation age of the

crop should be pre-determined to the extent that economic forecasting will permit. Other factors such as silvics, end products and optimum growth densities must be examined before the type and intensity of thinning can be prescribed.

Jack pine crop plans should consider the end product (pulpwood, sawlogs, poles) and whether thinning is a viable option. For jack pine, Day (1985) presents sample crop plans by yield class for pulpwood and sawtimber crops with and without thinning.

Although jack pine is favoured for sawtimber, the majority of its utilization from 'unmanaged' stands is as roundwood. Certain characteristics of jack pine are undesirable for sawlog production: a relatively short life-span, coupled with a growth slowdown between the ages of 10 and 20 years in dense fire origin stands (Armson 1978) and unacceptable high knot volumes in lower density stands (Janas and Brand 1988). Some of these deficiencies for sawlogs can be addressed through a thinning strategy.

The decision to thin or not to thin will depend upon both biological responses and economic gain. Economic analysis suggest that pre-commercial thinning is most practical for sawtimber production. Pre-commercial thinning has not yet been demonstrated to be financially positive for jack pine; that is, money spent on thinning plus the interest normally accrued on that money until rotation, is not covered by the more valuable and more harvestable timber (Smith et al 1986).

Consideration must also be given to current and anticipated timber supply and market situations, distance from manufacturing facilities, availability of capital and manpower and presence of potentially damaging agents.

WHEN TO THIN

Choosing the appropriate age and selecting an optimum density to thin to are important questions in the development of a stand.

Pre-commercial thinning should commence in jack pine when the lower lateral branches begin to die. This development stage is density-dependent, but often occurs between the ages of 6 and 12 years. Most authors agree that young stands will respond more favourably to thinning and this response diminishes rapidly with age (Hansen and Brown 1922; Cayford 1961). The most desirable age for thinning is controlled by the degree of response at the various ages and economic considerations (Smithers 1957).

The most economic time to thin is when the stand is approximately 10 years of age (Riley 1973; Bella and DeFranceschi 1974; Smith et al 1986). Trees at this age proved to be more responsive to thinning than older stands. Since thinning costs are lowest in younger stands (Riley 1973), these stands will yield the best economic results.

Suggested thinning densities for jack pine sawlog production are to a spacing of 2.0 x 2.0 to 2.5 x 2.5 m (2500 to 1600 stems per ha) if undertaken after the lower branches begin to die. The optimum density is dependent upon end product and the initial density. Caution should be used not to open up the stand too much as the cylindrical boles of natural or seeded jack pine are prone to wind, snow, and ice damage (Janas and Brand 1988). This could be critical in dense stands i.e. greater than 50,000 stems per hectare at age 10. In these dense stands, pulpwood may have to be produced as the potentially higher thinning costs may make sawlog production uneconomical.

Very little research has compared jack pine pre-commercial thinning regimes in terms of growth, yield and form differences. Mortality data following the

pre-commercial thinning until maximum mean annual increment is achieved is lacking, although it appears to be in the 15 to 20% range. In most studies suitable density (or spacing) levels were selected based upon experience and on limited research information. In Riley's (1973) and later Smith's (1984) study, prescribed spacing was 1.8m x 1.8 m, whereas the spacing achieved averaged 1.6m x 1.6 m. in a 9-year-old jack pine stand. Density was reduced from 13,170 to 3,906 stems per ha.

WHERE TO THIN

Pre-commercial thinning of jack pine has the greatest economic return on Site Class 1 and possibly on the upper half of Site Class 2 stands where sawlogs are to be the end product (Brown 1984). All other site classes (lower half of 2, 3 and 4) should be considered for extensive management (i.e. no thinning) for pulpwood. However, other factors, including reducing rotation ages or salvaging stands that might otherwise stagnate because of excessive densities must be considered.

With a Prime Site Strategy being considered in Ontario, the number of unregulated stands requiring thinning on prime sites in the future may be limited. However, in the event of large wildfires on these areas, natural or artificial seeding in conjunction with pre-commercial thinning may be the only option.

HOW TO THIN

Four methods are available for pre-commercial thinning of jack pine: manual, motor-manual, mechanical and chemical. Motor-manual thinning is the most common and efficient method used in northwestern Ontario.

Manual and Motor-Manual Thinning

Manual thinning will allow the manager to select the desired crop trees and to thin to a desired spacing. The ability to remove the suppressed, diseased and damaged trees is the major advantage of manual thinning. Large, dominant crop trees should have low taper, small branch diameters and be relatively free from disease and damage for sawlog production.

Portable circular power saws, 'brush-saws' or 'clearing saws' are used for motor-manual thinning and are the most common and efficient means of non-commercial thinning. Chainsaws have been used elsewhere in Canada for motor-manual thinning. Axes and sandviks are used in manual thinning. In a pilot scale thinning operation in northeastern Ontario, Riley (1973) reported that one person with a brush-saw could thin a hectare of 9-year-old jack pine from 13,170 stems /ha down to 3,900 in 10 hours. (i.e. 0.1 ha/hr). Using hand tools, the equivalent area required 18.9 hours. (.05 ha/hr). Bella (1974) carried out a manual thinning trial using brush-saws in 16-year-old lodgepole pine. He found the average time required to thin a hectare was 11.6 hours. (.08 ha/hr). For dense stands (up to 100,000 stems/ha) this figure nearly doubles to 19.0 hours/ha. (0.05 ha/hr). Bella (1974) suggests that when density increases to approximately 100,000 stems/ha there is no further increase in labour, as such small trees would hardly affect the performance of the saw. The entire area will have to be thinned when stands reach this density or greater. Although working with spruce-fir stands, Seymour et al (1984) and Ross (1982) clearly demonstrate the relationship between brush-saw productivity and density. They suggest that productivity levels off much below the 100,000 stems/ha level, at approximately 50,000 stems/ha.

Brush-saws can handle trees up to at least 8 cm in diameter but they are most effective when stems are under 5 cm. Brush-saws should be used in a swathing manner and cutting should be very rapid. For operational guidelines, readers are referred to the pamphlets prepared by the brush-saw manufacturers and "Juvenile Spacing - A Guide for Forestry Crews" (Anon. 1981).

Average costs of contract brush-saw thinning during 1986 and 1987 in northwestern Ontario have been in the range of $300 to $350 per ha. Minimum costs have been in the $225 per ha range, with a maximum of $450 per ha.

Currently, some 800 ha of pre-commercial thinning is completed annually using primarily brush-saws in northwestern Ontario. Almost all of this thinning is undertaken in Northwestern Region, most notably in Dryden District. With greater emphasis on lower initial cost regeneration, it is anticipated that the amount of pre-commercial thinning will moderately increase in the next 4 to 6 years.

Mechanical Thinning

In order to make pre-commercial thinning more economically attractive, various non-selective multi-stem mechanical thinning techniques have been devised. These have included the use of discs, dozer blades, rakes, drum choppers and mowers (Dunfield 1974; Ryans 1987). Virtually all the mechanical non-commercial thinning has been of a row or strip nature (Riley 1973). Mechanical thinning does not offer the freedom of choosing which trees are to be culled but may thin large areas more cost effectively (Bella 1972).

Mechanized pre-commercial thinning has been of interest for years but to date the technology has not been developed to meet both the biological and economic requirements. The lack of success of mechanized thinning systems can

be attributed to: poor mechanical integrity of the units; wide size requirements of the prime mover; stand densities must be high to justify the machines; and the requirement of uniform terrain conditions. (Smith 1987; Ryans 1987) None of the existing equipment appears to meet the necessary criteria.

A drum-chopper dragged by a crawler-type tractor was the most effective for mechanical strip thinning of pine stands in Alberta and Manitoba (Bella and DeFranceschi 1971; Bella 1972). Unfortunately, this technique is unsuitable if numerous large, dead trees are standing in the young stands, such as after fire, or if large size slash and/or boulders are present.

Most studies of mechanical thinning have shown only poor to moderate success in terms of growth response (Steneker 1969; Bella 1974; Alm et al. 1979). Skilling (1957) showed that reducing the width of leave strips from 1.8 to 0.9 meters improved the growth response. Bella (1974) concluded that unless improvements in growth occur, mechanical strip thinning could not be justified.

Mechanical thinning can increase the stand's susceptibility to damage and disease. Trees along the edges of the residual strips may be damaged and may exhibit an increased susceptibility to disease.

Mechanical thinning may be viable if combined with manual selective thinning within the residual strips (Smith 1984). This combined thinning method could only be undertaken on sites that are free of large stumps, boulders and windfall. Smith (1987) suggests that combined mechanical and motor-manual thinning is probably only justified where densities are high; this would ensure adequate crop tree selection and reduce motor-manual costs. Machines are less affected by increasing density than are people; therefore, as density increases, machines become more viable.

Chemical Thinning

Chemical control of density in young conifer stands has been addressed in the literature but does not appear to be a viable operational technique. Conclusive data on the appropriate chemicals, dosages, method of application and long term environmental impacts have not been addressed. A number of the tested herbicides are either no longer registered for forestry applications (i.e. 2,4,5-T) or have never been registered in Ontario.

Chemical tending has been tested both as aerial and ground applications. With aerial applications, Riley (1973) makes reference to using Tordon 101 applied by helicopter in strips and cross-strip patterns at 2.1 meter spacing. Follow-up data on this trial indicates that the kill strips were satisfactorily controlled (Riley 1974), but no further growth response data has been published. McCormack (1987) evaluated 12 herbicides using helicopter-applied bands for adjusting density in developing spruce-fir stands in Maine. Promising results were achieved with dicomba and picloram and the addition of 2,4-D provided additional effectiveness.

Ground chemical tending has been tested as strip or block thinning in lodgepole pine (Crossley 1956) or as selective thinning using a silvicide in jack pine (Riley 1974). Crossley (1956) found the herbicides 2,4-D, 2,4,5-T and Brushkiller to be effective in reducing the density of young, overdense, stagnating lodgepole pine stands when applied during the spring or midsummer. Operationally, this type of chemical ground thinning would be difficult to control and is not recommended.

Hypohatchets which use cacodylic acid as a silvicide for injecting into trees have been tested by several authors (Day 1965, 1967; Riley 1973). This type of treatment is usually performed on larger trees with excellent results.

Hypohatchets can be effectively used on jack pine greater than 5 cm dbh since smaller stems are very flexible and do not offer sufficient resistance to the hatchet blow (Riley 1974).

OTHER CONSIDERATIONS

Pre-commercial thinning can be one of the most important silvicultural treatments in the development of a jack pine stand. However, several additional factors must be considered before a pre-commercial thinning program is initiated. These include biological considerations, insect and disease susceptibility, damage, payment method and economic considerations.

Biological Considerations

The thinning of jack pine can suddenly alter the stand's ecosystem. Soil moisture, vegetative ground cover, animal habitat, insect and disease development, and species' physiological characteristics are some of the properties affected.

Soil moisture availability has increased after thinning in lodgepole pine (Goodell 1952; Dahms 1971, 1973). Increased ground interception of precipitation from the reduced crown cover and increased winter snow cover led to more absorption of water into the soil. The increased soil moisture associated with lower stand densities from thinning may lead to increased availability of water into the drier summer months to promote a longer active growing season. Some of this water may result in increased understory forage (Dahms 1973) or potential for increased stream flow.

Thinning has increased the diversity of species in understory vegetation in lodgepole pine (Crouch 1986). Studying the effects of thinning pole-sized

lodgepole pine on understory vegetation and large herbivore activity in central Colorado, Crouch (1986) found thinning increased understory species diversity. Subsequent plant utilization from herbivore activity was observed to increase. In addition, thinning had the effect of easier accessibility to these stands by larger animals, notably deer and elk; however, in high density juvenile stands, slash from pre-commercial thinning can create accessibility problems for wildlife.

Insect and Disease Susceptibility

Insect and disease problems can increase in thinned areas as compared to unthinned control areas. This may be a result of the slash left following thinning serving as a reservoir for insects and pathogens which can attack the residual trees. A higher incidence of attack by common pest organisms in thinned lodgepole pine was reported by Bella (1985): based on a sample of nearly 3,000 potential crop trees, the rate of western gall rust increased from 18% on unthinned stands to 30% on thinned stands; damage by terminal weevil and pitch twig moth increased from 10 to 25% in unthinned vs. thinned stands. Van der Kamp and Spence (1987) reported similar observations for western gall rust, stalctiform and comandra blister rust, and atropellis canker. Five years after thinning, 25% of the trees in unthinned control areas were unhealthy compared with 40% in thinned areas.

Western gall rust and possibly dwarf mistletoe may be potential disease problems following thinning in northwestern Ontario. The development of dwarf mistletoe is favoured by light thinnings or selection cuts which generally stimulate the rate and severity of infection. The wider spacings following thinning may create favourable conditions for spore dispersal. Dwarf mistletoe

on jack pine has been reported as a problem in Kenora district (Powell 1970). In natural stands and plantations, Chong and Juzwick (1988) found no correlation between the density of jack pine stems and western gall rust incidence, but thinned jack pine stands were not sampled. Recent observations suggest that wildfires may have eradicated much of the problem.

Potential insect and disease problems can be managed by ensuring that cut trees are placed as close to the ground as possible to accelerate decomposition and that none of the cut trees rest against crop trees.

Damage

Care must be taken during a manual or motor-manual thinning operation. Cuts or nicks on the crop trees can result in the death of the tree or increase its susceptibility to insect and disease problems. In addition, small cuts can make the tree susceptible to wind and snow damage.

Payment Method

It is recommended that payment for pre-commercial thinning of jack pine be based on an area basis (cost per ha) with a quality control provision. The objective must be to obtain the best quality treatment for the least cost. Since productivity is affected by stand density, payment (tender) rates will vary with variations in stand density. Factors that should be addressed in the quality control procedure are crop tree selection, density, spacing, damage and slash disposal. A clear sampling and assessment procedure must be in place prior to the work being initiated.

Economic Considerations

As previously stated, the economics of thinning jack pine suggests that pre-commercial thinning at sapling stage (ages 6 to 12 years) for sawtimber production on the higher site classes provides the greatest economic return. This is especially important if a sawmill is faced with a future shortage of quality sawlogs. The amount of literature on the economics of pre-commercial jack pine thinning is limited. The reason may be that the financial returns of investment will not be realized until final harvest. The implications of an ever-changing economic climate are difficult to predict to harvest time.

One of the greatest benefits of pre-commercial thinning may be a reduced harvesting cost per unit volume removed from the mature stand. Unfortunately, we do not have the economic data to support this and other long term growth responses and effects.

The earlier a stand can be put into an optimum biological spacing, the greater chance it will have to utilize the full potential of the site (Riley 1973). Smith et al (1986) did an economic analysis of the results of two non-commercial thinnings in 9 and 22-year-old stands. They found the stand thinned at 9 years of age yielded a higher rate of return because of the high cost of treatment in the 22-year-old stand. Riley (1973) noted from his studies that the most favourable time to thin economically coincides with the most favourable time biologically.

Smith et al (1986) illustrates through sensitivity analysis that marginal increases in growth response over those recorded in the case study (Site class II stands) would result in profitable investment. The authors stated that positive economics have not been demonstrated. There has been insufficient testing of response over a range of sites to identify if and where better growth

may be achieved. Thus there remains the possibility that better results could be demonstrated.

The economics of establishing a jack pine crop by seeding and pre-commercial thinning makes financial sense when compared to planting. Assuming the costs of site preparation and competition control for both methods are equal, the approximate cost of establishment by planting would be $625.50 /ha while seeding and pre-commercial thinning would cost $424.30 /ha (excluding site preparation). The costs for establishment by planting include the cost of seed ($5.50 /ha), production of container stock ($290.00 /ha), transportation to the planting site ($20/ha) and the cost of planting ($310.00 /ha) for a total of $625.50 /ha. In comparison the cost for direct seeding and pre-commercial thinning is approximately $424.30 /ha which includes $67.00 for seed collection and extraction, $7.30 /ha for aerial seeding and $350.00 /ha for thinning with brush saws. Economic analysis of seeding followed by pre-commercial thinning when compared to planting shows a higher maximum annual annuity for seeding and pre-commercial thinning (Willcocks et al. 1988). The greater economic investment efficiency of seeding and pre-commercial thinning is in part a result of the delay of up to 6 to 12 years to incur the investment when compared to planting.

SUMMARY AND CONCLUSIONS

Pre-commercial thinning of jack pine is an important silvicultural tool to control the density and development of overstocked stands. Rotation ages can be reduced as well as increasing the merchantable volumes by producing larger, more valuable trees. The total yield or site capacity, however, remains constant. Growth response increases are reported for diameter and basal area, while height remains relatively unaffected. By thinning, mortality of the trees remaining in a stand can be substantially reduced. While pre-commercial thinning can produce an increase in merchantable volume, the quality of the wood can be affected. More juvenile wood is produced by the increased growing spacing created through thinning. Just how wide the spacing needs to be before wood is affected is unknown for jack pine. Selective thinning of jack pine in natural or direct seeded stands can produce higher quality sawlogs than planting unimproved stock at normal or wide spacing (Janas and Brand 1988).

Pre-commercial thinning has the greatest economic return on site class 1 and possibly on the upper half of site class 2 jack pine stands where sawlogs are to be the end product. If fibre is the primary product, pre-commercial thinning can be considered where there is a need for reduced rotation age or for salvaging stands that might otherwise stagnate because of excessive density.

Pre-commercial thinning should commence in jack pine when the lower branches begin to die. This development stage is dependent upon the initial density but usually occurs between the ages of 6 and 12 years.

Motor-manual thinning with brush-saws is the most efficient method of thinning jack pine, although manual thinning with axes or sandviks is a good low cost alternative. Manual and motor-manual thinning allows the freedom of selecting the crop trees and maintaining spacing between them. Mechanical strip

thinning has not proven to be effective, but it could be useful if followed by a manual, selective thinning. Most mechanical thinning operations have been of a rowed or strip nature in which mechanical integrity of the units, size of prime mover and terrain conditions were critical factors in the economics and lack of success of these trials. Chemical thinning has been attempted but does not appear to be a viable option at this time.

Crop tree selection is one of the most important considerations of the thinning operation. The potential crop tree must be assessed for its relative position, condition of the crown, health of the tree, and the condition and quality of the bole.

Pre-commercial thinning has a positive influence on soil moisture, vegetative ground cover and animal habitat. Negative characteristics of thinning are found in the development of insect and disease problems.

The economics of pre-commercial thinning of jack pine has yet to be proven but reports indicate thinning around the age of 10 years for sawlogs will give the best biological and economic results. Economic testing using current investment costs must be undertaken at the local level. Consideration must be given to current and anticipated timber supply and market situations.

Areas for further development and research were identified and included the influence of pre-commercial thinning of jack pine on: stem taper; fibre length; mortality after thinning to assist in determining suitable density levels to thin to; testing of thinning responses over a range of sites to identify if and where better growth may be achieved.

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